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Extraction of OAEs During Multi-Frequency ASSR Recordings With the Goal to Estimate Peripheral Compression

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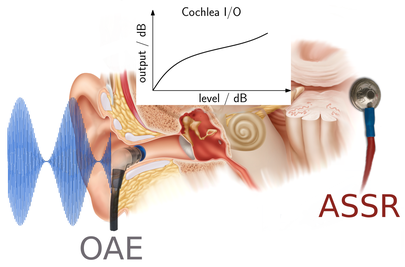
Abstract

Auditory steady-state responses (ASSR) allow objective assessment of auditory function using electroencephalography (EGG). If peripheral compression is, at least partially, due to cochlear compression, the amplitude of ASSR as a function of level can be assumed to reflect the compressive growth of the cochlear nonlinearity. A recent study (Encina Llamas et al., ARO2014) showed, that compressive input-output functions with slopes similar to proposed compression ratios of cochlear level-growth functions can be found using ASSR obtained by stimulation with multiple sinusoidally-amplitude-modulated (SAM) tones. The goal of the current study is to investigate the estimation of cochlear compression using the same stimuli as used for ASSR (SAM tones).

Hypothesis

Peripheral compression is reflected in level-growth functions of auditory-steady state responses (ASSR) evoked by sinusoidally-amplitude modulated tones. The stimulus used to evoke the ASSR produces an otoacoustic emission (SAMOAE) in the ear canal. This SAMOAE is a modulated stimulus-frequency OAE and can be used to estimate cochlear compression.



Methods

The OAE was extracted by assuming that the probe signal p_{probe} contained the OAE p_{OAE} and the stimulus p_0

$$p_{OAE} = p_{probe} - p_0$$

SFOAE

- 3-interval paradigm adpted from Shairer et al. (2003) and Kalluri&Shera (2007)
- Fixed suppressor level at 65 dB SPL, $f_s/f_{sig} = \mathbf{0.88}$
- Compressor level $L_{comp} = L_{sig} + \mathbf{6}$dB

SAMOAE

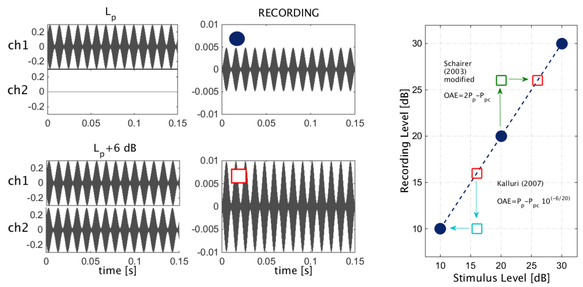


FIGURE 1: *Compression paradigm to extract SAMOAEs. The stimuli were the same SAM tones as in Encina Llamas et al. (2014) (centre frequencies of {498 Hz,1002 Hz,2005 Hz,4011 Hz} and modulation frequencies of {81 Hz,87 Hz,93 Hz,98 Hz}). Two intervals with a level difference of 6 dB were used apply a compression paradigm similar to Shairer et al. (2003). Signals were generated and recorded using a RME Fireface Fireface 800 soundcard. The stimuli were attenuated (TDT HB7) and presented using an Etymotic ER-10B+ probe. Recordings were band-pass filtered (300 Hz-6000 Hz, Krohn-Hite) before.*

Individual Results

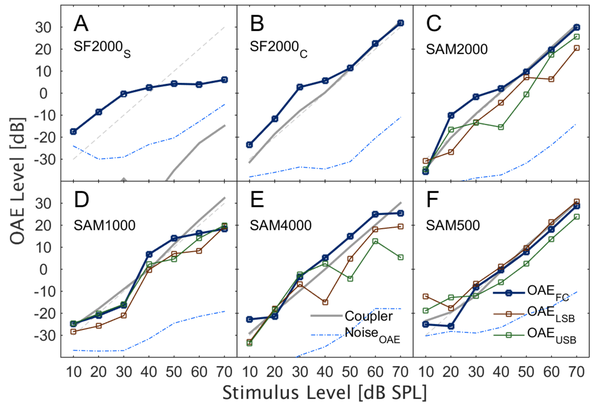


FIGURE 2: *Results for subject AGZ. SFOAEs obtained with a suppression (A) and compression (B) paradigm. Panels C-F show SAMOAEs obtained at centre frequencies of 2000 Hz, 1000 Hz, 4000 Hz, and 500 Hz. The thick grey line indicates the same*

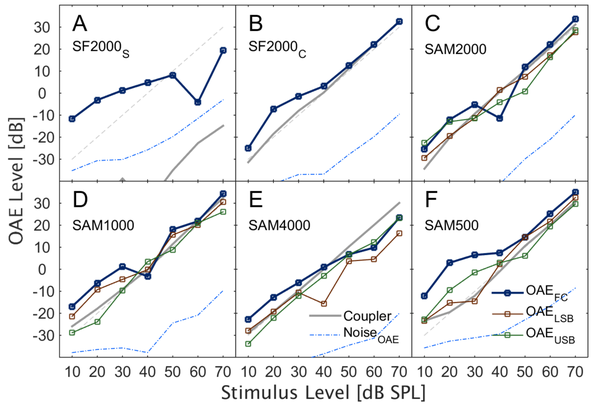


FIGURE 3: *Same as FIG 2, but for subject APJ*

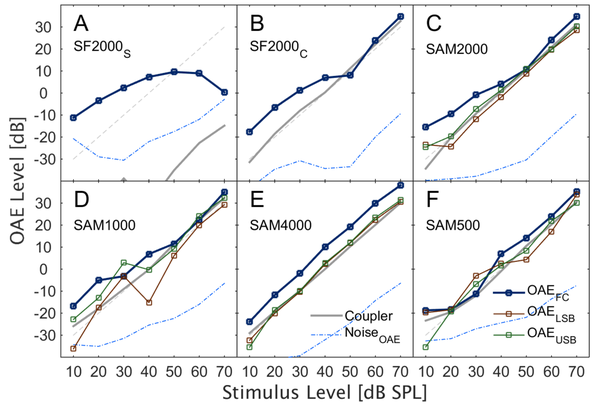


FIGURE 4: *Same as FIG 2, but for subject MFR*

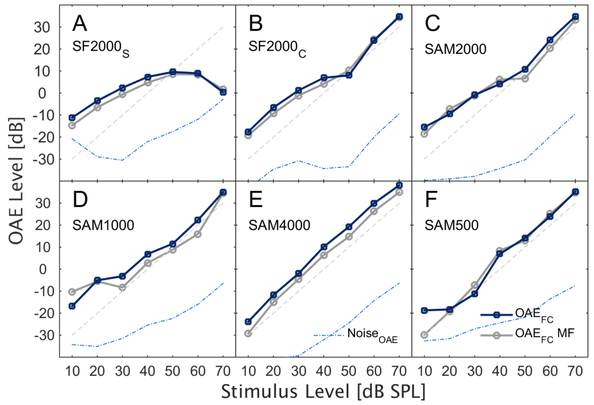


FIGURE 5: *Same as FIG 4, but for stimulation **with all 4 components simultaneously**. The suffix MF denotes the multifrequency condition.*

Analysis of coupler nonlinearities

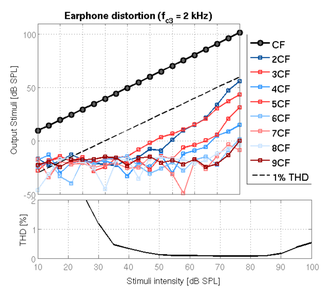


FIGURE 6: *Upper panel: Levels of primary tone (2000 Hz) and harmonic components measured for the probe placed in a coupler. Lower panel: Time harmonic distortion (THD) as a function of input level.*

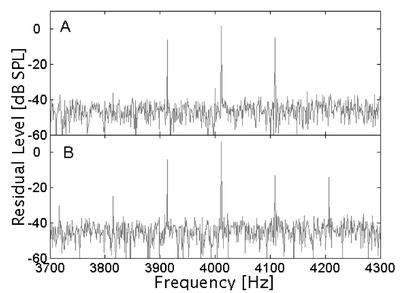


FIGURE 7: *Spectral analysis of the derived OAE (p_{OAE}) in the in coupler (A) and ear canal (B) with stimulation of the SAM tone centred at 4000 Hz. While hardly any distortion could be found in the coupler, the ear canal recording shows a lot of distortion components.*

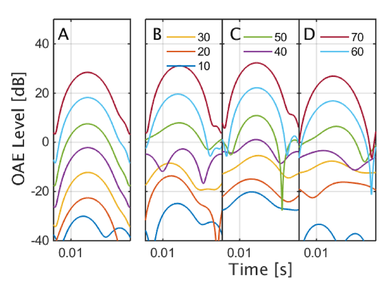


FIGURE 8: *Heterodyne analysis of a recording in the coupler (A) and in three different ears (B-D). While the envelope grows linearly in the coupler, a more complex pattern could be found for the tested ears.*

Discussion

Physiological measurements:

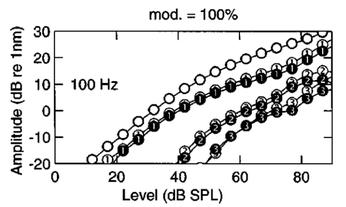


FIGURE 9: *Response of the basilar membrane of a chinchilla cochlea to a SAM tone with 100 Hz modulation frequency (Rhode & Recio, 2001). Both, the carrier and to the side bands increases linearly for low levels and shows compression at higher levels.*

- Physiological measurements show compressive growth for SAM stimuli
- Levels of side bands increases similar to carrier for lower modulation frequencies (≈ 100 Hz)
- Linear reflection components at BF should also reflect this compressive growth

EEG measurements:

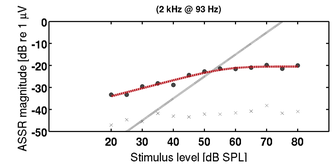


FIGURE 10: *Magnitude of the ASSR over a level range between 20 and 80 dB input level. The ASSR shows a compressive growth over the whole frequency range, with stronger compression for levels > 50 dB SPL (Encina Llamas et al., 2014)*

- ASSR does not show linear growth at low levels, indicating retro-cochlear compression
- Transition towards higher compression at similar level then in physiological measurements?

Conclusion

⇒ Extraction of SAMOAE possible using the sinusoidally-amplitude modulated tones

⇒ Compression paradigm in connection with transducer distortion might obscure results at levels > 50 dB SPL

⇒ Simultaneous measurement of ASSR and SAMOE might contribute to identify cochlear and retro-cochlear contributions

⇒ Since no additional time expense, potential application in audiological practice

Acknowledgements

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